A Scanning Multichannel Microwave Radiometer for Nimbus-G and Seasat-A

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Abstract

A scanning multichannel microwave radiometer (SMMR) has been designed for the Nimbus-G spacecraft and incorporated also into the SeaSat-A payload for the primary purpose of determining sea surface temperatures and wind stress on a nearly all-weather basis. Observations of microwave polarization components will be made at wavelengths of 0.8. 1.4, 1.7, 2.8, and 4.6 cm over a swath 822 km wide below the Nimbus-G and 595 km wide below the SeaSat-A spacecraft. The smallest spatial resolution cell is about 20 Pan at a wavelength of 0.8 cm, and proportionately larger at the other wavelengths. Using algorithms based on a combination of experimental data and physical models for converting the observed brightness temperatures, the indicated accuracies of the results (excluding conditions of significant rainfall) are within 1 K for sea surface temperature and 2 m/s for surface wind speeds, over a range from 0-50 m/s.

under study at the present time using artificial data sets obtained by calculating a set of brightness temperatures for all ten SMMR channels from (1) and an appropriate set of the five parameters.

For the purposes of an approximate illustration, a different approximation technique will be discussed here which involves looking at subsets of the ten brightness temperatures to be obtained from SMMR.

Equations (2)–(4) indicate that the atmospheric opacity is less than unity for the wavelengths of 2.8 and 4.6 cm for a wide variety of atmospheric conditions. This, in turn, implies that a Taylor expansion of (1) about the value of $\tau = 0$ can be used in good approximation to provide a linear set of equations which may be formally solved for the surface and atmospheric parameters contained therein. We initially concentrate on obtaining the ocean surface temperature and ocean surface wind speed, treating the atmospheric opacity simply as a correction factor, and utilize only three of the ten channels. In this case, we use the following linearized form for (1) [26]:

$$T_{Bij} = t_{0ij} + S_{ij}t_s + V_{ij}v + T_{ij}\tau_i \tag{7}$$

where

$$t_{0ij} = \epsilon_{0ij}(T_0 - T_{spi}) + T_{spi}$$

$$S_{ij} = \epsilon_{0ij} + \epsilon_{sij}(T_0 - T_{spi})$$

$$V_{ij} = \epsilon_{vij}(T_0 - T_{spi})$$

$$T_{ij} = 2(1 - \epsilon_{0ij})(T_0 - T_{spi}) - t_1 - (1 - \epsilon_{0ij})t_2$$

i refers to wavelength, j refers to polarization, $t_s = T_s - T_0$, T_0 is the *a priori* local surface temperature, and t_1, t_2 are temperature *differences* between T_S and the temperature at some points below the freezing level in the clouds, obtained from a weighted averaging over the cloud layers. A fixed value of 20 K for t_1 and t_2 has been assumed here for the purposes of illustration. The linear coefficients in (7) were obtained by performing a first-order Taylor expansion of (1).

The vector form of (7) may be written as

$$\boldsymbol{T_B} - \boldsymbol{t_0} = \bar{A} \cdot \boldsymbol{P} \tag{8}$$

where

$$\boldsymbol{P} = (t_s, v, \tau_{4.6}).$$

Using the value of 3 K for T_{spi} at all wavelengths, 271 K for T_0, values of ϵ_{0ij} and ϵ_{sij} obtained from published values of the complex index of refraction of 3.5-percent NaCl in water [24] and values of ϵ_{vij} extrapolated to a 50° viewing angle from the curves of Fig. 5, the matrix A has the following elements:

$$\bar{A} = \begin{pmatrix} 0.26 & 1.08 & 382.4 \\ 0.53 & 0.40 & 249.7 \\ 0.13 & 1.32 & 971.4 \end{pmatrix}. \tag{9}$$

The formal solution of (8) is

$$\begin{pmatrix} t_s \\ v \\ \tau_{4.6} \end{pmatrix} = \begin{pmatrix} -0.229 & 2.11 & -0.452 \\ 1.870 & -0.786 & -0.534 \\ -0.0025 & 0.0008 & 0.0018 \end{pmatrix} \cdot \left[\begin{pmatrix} T_{4.6H} \\ T_{4.6V} \\ T_{2.8H} \end{pmatrix} - t_0 \right]. \tag{10}$$

In principle, (10) can be used with a measured set of brightness temperatures from the 2.8- and 4.6-cm wavelength channels of the SMMR to obtain values for the ocean surface temperature, the 20-m ocean surface wind speed, and the atmospheric opacities at the two wavelengths. It is emphasized that the values in the matrices of (9) and (10) are based on preliminary values of ϵ_{vij} and are shown here only for illustrative purposes.

The noise amplification factors for the various parameters are obtained by taking the root-mean-square average of the elements in each row of the matrix $\bar{A}^{-1}$ in (10). Thus, for the case illustrated here, the noise amplification factor for both the surface temperature and the 20-m surface wind is about 2. This implies that a noise figure of 0.2 K (obtainable by averaging a suitable number of resolution cells) for each of the three SMMR channels under discussion leads to noise in the determinations of ocean surface temperature and 20-m wind speeds of 0.4 K and 0.4 m/s, respectively. Of course, it should be understood that these error estimates apply only to the instrument contribution to the total error; the fact that linear regression fits have been made to nonlinear phenomena will also contribute to the total error in the determinations. This latter factor can be controlled by limiting the allowable range of parameter values in a given data inversion. The validity of these estimates also depends strongly on the correctness of the physical model used for the T_B variation with windspeed.

If T_s and v are assumed to be constant over the entire 4.6-cm wavelength spatial resolution cell, the values obtained from (10) could be used in (7) to solve for the atmospheric opacity at each of the five wavelengths. The atmospheric parameters of water vapor content, liquid water content, and rainfall rate could be deduced from the values of the individual opacities and their ratios. In addition, if the opacities are sufficiently small at the shorter wavelengths, the 0.81- and 1.7-cm channels could be used as illustrated in (8) and (10) to obtain sea surface temperature and 20-m wind speeds within a smaller resolution cell (but at reduced sensitivities), i.e., within a 46-km cell rather than a 125-km cell. This and a number of other alternative approaches will be evaluated further before a final selection is made of the algorithms to be used for routine processing of the SMMR data.

V. CONCLUSIONS

A multispectral passive microwave imager has been designed and is under construction with sensitivities sufficient for accurate determinations of sea surface temperature, wind speeds, atmospheric liquid water content, water vapor, and rainfall rates over oceans. Based on demonstrated noise figures of the radiometer components and *a priori* knowledge of the parameters at a given geographical location, it is estimated that ocean surface temperature determinations might be made with an accuracy of 1 K or less and wind speed determinations within 2 m/s, with the precautionary that these estimates assume that a good linear fit can be made to the dependence of microwave brightness temperatures on these parameters. This assumption may not be valid for the wind speed determination, as has been discussed in the text. The actual accuracies achievable will have to be determined by subsequent experimentation on board both the spacecraft and aircraft platforms. It should be emphasized that all of the coefficients appearing in (7) are subject to change in the final algorithms. They will be determined by regression analysis of observed brightness temperatures and measured surface/atmosphere parameters.

The development of algorithms for the SMMR is certainly not complete at this point. Prior to the launch of Nimbus-G and SeaSat-A, extensive additional experiments on board aircraft along with *in situ* comparative measurements will be carried out. It is anticipated that improved radiometers on board the aircraft, better techniques for obtaining surface wind speeds, and a broader statistical data base will all contribute to a better definition of the constants involved in the aforementioned linear regressions. Future work in this area will be a cooperative effort of the members of the experiment teams for both the Nimbus-G SMMR and the SeaSat-A SMMR.

The SMMR represents the first opportunity for obtaining important oceanic parameters on a nearly all-weather basis from spacecraft-borne remote sensors. The spatial resolution available with the SMMR is not as good as would be desired for some applications. However, the SMMR does provide an important first step in the development of larger instruments to be carried on future spacecraft, e.g., the shuttle, which can carry larger microwave antennas. Such instruments are under development at this time.

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